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ANNUAL REPORT

Joint Services Electronics Program

DAAG29-81-K-0024

April 1, 1981-March 31, 1982

TWO-DIMENSIONAL SIGNAL PROCESSING AND STORAGE AND THEORY AND APPLICATIONS OF ELECTROMAGNETIC MEASUREMENTS

August 1982
School of Electrical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is an annual report on research conducted under the auspices of the Joint Services Electronics Program. Specific topics covered are: digital signal processing, parallel processing architectures, two-dimensional optical storage and processing, hydrid optical/digital signal processing, electromagnetic measurements in the time domain, and automatic radiation measurements for near-field and far-field transformations.

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I. INTRODUCTION

This is an annual report on research carried out under Contract DAAG29-81-K-0024 during the period April 1, 1981 through March 31, 1982. The research activities were concentrated in two areas: 1) Two-Dimensional Signal Processing and Storage, and 2) Theory and Applications of Electromagnetic Measurements.

The research in two-dimensional signal processing and storage focuses on four major areas which overlap and reinforce one another. Digital Signal Processing research deals with the theory, design, and application of digital signal representations and digital signal processing algorithms and systems. The research in Parallel Processing Architectures is concerned with hardware and software problems in the use of multiport memories and multiple microprocessors for high-speed implementations of signal processing algorithms. The Two-Dimensional Optical Storage and Processing research efforts have focused upon holographic storage of information in electro-optical crystals and upon digital signal processing operations that can be incorporated with storage and retrieval functions. Hybrid Optical/Digital Signal Processing is concerned with the theory, implementation, and application of combined optical and electronic digital signal processing techniques. Details of the research in this general area are given under Work Units Number 1 through 6.

The research in electromagnetic measurements is focused upon two major areas. Research in Electromagnetic Measurements in the Time Domain has centered on the development of new methodology for making time domain measurements. The work involves both theoretical and experimental investigations of the use of transient signals to measure the characteristics of materials and electromagnetic systems. Research in Automated Radiation Measurements for Near- and Far-Field Transformations has been concerned with assessing the accuracy of computed fields on the surface of lossy radomes and with compensating for probe effects when near-field measurements are made on arbitrary surfaces. Particular attention is devoted to spherical surfaces. This research is described under Work Units 7 and 8.

II. SIGNIFICANT RESEARCH ACCOMPLISHMENTS

The year covered by this report has produced many useful and potentially important results. These results are documented in the two theses, the 19 conference presentations, the 17 journal articles and the 3 book chapters listed in this report. The following accomplishments are, in the judgement of the laboratory directors, of particular significance and worthy of special consideration.

2.1 Rigorous Coupled-Wave Theory

For the first time, a state variables approach from linear systems theory has been applied to solve the grating diffraction problem. This has been done rigorously and has resulted in a method of solution without approximations! With this very powerful and exact method of analysis, previously used approximations (neglect of second derivatives, neglect of higher-order waves, and neglect of boundary diffraction) have been evaluated for the first time. The resulting publications are being cited by many workers. The papers are:

Moharam, M.G. and Gaylord, T.K., "Rigorous coupled-wave analysis of planar grating diffraction," Journal of the Optical Society of America, vol. 71, pp. 811-818, July 1981.

Moharam, M.G. and Gaylord, T.K., "Coupled-wave analysis of reflection gratings," Applied Optics, vol. 20, pp. 240-244, January 15, 1981.

2.2 Automatic Optical Implementation of Recursive Signal Flow Graphs on Synchronous Multiprocessors

A new approach for the implementation of single time index signal flow graphs has been developed and tested. The procedure takes a simple non-parallel algorithm description and generates from it a fully parallel optimal implementation for synchronous multiprocessor systems composed of many identical processors. This approach, which utilizes the Skewed Single Instruction Multiple Data (SSIMD) mode whenever possible, is applicable to many classes of multiprocessors ranging from arrays of general purpose computers to VLSI multiprocessor implementations or a single chip.

2.3 Technique for Compensation of Probe Position Errors in Near-Field Measurements

An approximate correction for probe position error in near-field antenna measurements has been developed, and shown to be accurate for small probe position errors. This approximate technique called "K-correction" is a phase only correction which is based on the assumption of all near-field energy propagating in the K-direction of the main beam peak. This technology has been transferred to the RCA, U.S. Navy Aegis program and is now in use. Alignment of the Aegis phased array was judged to be impossible without the K-correction technology.

WORK UNIT NUMBER 1

TITLE: Constrained Iterative Signal Restoration Algorithms

SENIOR PRINCIPAL INVESTIGATORS

R. M. Mersereau, Associate Professor
R. W. Schafer, Regents' Professor

SCIENTIFIC PERSONNEL

C. C. Davis, Graduate Research Assistant (Ph.D. candidate)
C. F. Earnest, Graduate Research Assistant (M.S. June 1981)
A. K. Katsaggelos, Graduate Research Assistant (Ph.D. candidate)
R. Marucci, Graduate student (M.S. June 1981)
A. Scarasso, Graduate student (M.S. December 1981)

SCIENTIFIC OBJECTIVES

The objective of this research is to study a broad class of iterative signal restoration techniques which can be applied to remove the effects of many different types of linear and non-linear distortions through knowledge of the distortion operator and a' priori constraints on the set of allowable signals. Specific attention is directed to the reconstruction of signals from their projections and the removal of spatially-varying blurs from imagery.

RESEARCH ACCOMPLISHMENTS

The Master's thesis by Marucci showed that the fixed-point iteration for constrained deconvolution, based on Van Cittert's unconstrained iteration, which we have explored extensively in the past is equivalent to a functional minimization. A more rapidly converging algorithm results by using the conjugate gradient algorithm to perform this minimization. The conjugate gradient approach is also directly applicable to the iterative implementation of a 2-D recursive digital filter which has been recently introduced by Dudgeon.

The algorithm which Marucci developed minimizes a quadratic functional. The deconvolution problem can also be solved by an algorithm which minimizes an ℓ_1-norm (i.e. minimizes the absolute value of the error). This problem cannot be solved using a gradient algorithm but can be solved using a linear program. A small version of the ℓ_1-algorithm has been programmed and works well.

A major advantage of the iterative approach is that the equations involved in the signal restoration algorithm are formulated in terms of the distortion operator itself rather than its inverse. This is particularly important in problems where the inverse operator either does not exist or is difficult to determine and implement. This is the case for example in where the distortion is linear but shift-variant. We have begun to explore the application of iterative algorithms for shift-varying distortions such as might be encountered in non-uniform motion blur. Promising preliminary results have been obtained which indicate a need for more theoretical study of the convergence properties of iterative algorithms for shift-variant distortions.

PUBLICATIONS AND PRESENTATIONS

1. R. Marucci, "Signal recovery from the effects of a non-invertible distortion operator," M.S. Thesis, June 1981.

2. R. Marucci, R. M. Mersereau, and R. W. Schafer, "Constrained iterative deconvolution using a conjugate gradient algorithm," Proc. 1982 IEEE International Conference on Acoustics, Speech, and Signal Processing, pp. 1845-1848, 1982.

WORK UNIT NUMBER 2

TITLE: Spectrum Analysis and Parametric Modelling

SENIOR PRINCIPAL INVESTIGATORS

R. W. Schafer, Regents' Professor
R. M. Mersereau, Associate Professor

SCIENTIFIC PERSONNEL

T. C. Speake, Graduate Research Assistant (Ph.D. candidate)
P. A. Maragos, Graduate Research Assistant (Ph.D. candidate)
E. W. Brown, III, undergraduate student

SCIENTIFIC OBJECTIVE

The objective of this research is to study and develop new techniques for spectrum analysis of one- and two-dimensional signals and to study the use of this analysis in the modelling of one- and two-dimensional signals.

RESEARCH ACCOMPLISHMENTS

One major area of interest is in the processing of hexagonally sampled signals. Before this research was performed, it was recognized that hexagonal sampling of isotropic two-dimensional signals offered substantial savings over the traditional rectangular sampling which is invariably used. The limitation with hexagonally sampled signals was that it was felt that traditional signal processing operations, such as digital filtering and discrete spectral analysis could not be performed using a hexagonal representation. Our work has shown this to be false; not only can signal processing algorithms be performed using such a representation, but they can often be implemented with less computational effort than with the traditional rectangular representation. Our work has led to the development of a number of signal processing algorithms based not only upon hexagonal sampling, but also upon more general periodic sampling representations.

During the past year we have addressed and solved the problems of decimating and interpolating signals defined on any periodic sampling lattice. Included in this work are algorithms for converting from one lattice to another. We have also shown that any discrete Fourier transform algorithm can be evaluated using a row-column algorithm and have programmed this algorithm.

The other area of major emphasis has been autoregressive models for images. In this area we have investigated a number of questions concerning the implementation of two-dimensional linear predictors. We have found that the positive nature of image signals requires a somewhat different linear prediction formulation than is used for signals which have no bias. Results indicate that significant improvements in the stability of corresponding image models can be achieved by proper attention to the estimation of the average value of the image. Preliminary results also indicate signifiant advantages in applying autoregressive modelling to the logarithm of the image intensity samples rather than the intensity samples themselves.

The results of our studies have been applied to the design of an adaptive differential PCM image coding system. By using both adaptive prediction and adaptive quantization on small sub-regions of an image, we have been able to achieve good image fidelity at bit-rates well below one-bit/pixel. Such coding schemes are potentially applicable to efficient transmission of signals such as FLIR images.

PUBLICATIONS

1. R. M. Mersereau and T. C. Speake, "Multi-dimensional digital signal processing from arbitrary periodic sampling rasters," 1981 International Conference on Digital Signal Processing, pp. 93-101, Florence, Italy, September 1981. Also presented at the NSF Italy - USA Workshop on Digital Signal Processing, LaSpezia, Italy, August 1981, pp. 122-130 (invited).

2. R. M. Mersereau and T. C. Speake, "A unified treatment of Cooley-Tukey algorithms for the evaluation of the multi-dimensional DFT", IEEE Trans. on Acoustics, Speech, and Signal Processing, vol. ASSP-29, pp. 1011-1018, October 1981.

3. P. A. Maragos, R. M. Mersereau and R. W. Schafer, "Some experiments in ADPCM coding of images," 1982 IEEE International Conference on Acoustics, Speech and Signal Processing, pp. 1227-1230, May 1982.

4. R. M. Mersereau and T. C. Speake, "The processing of periodically sampled multi-dimensional signals," submitted to IEEE Transactions Acoustics, Speech and Signal Processing.

WORK UNIT NUMBER 3

TITLE: Signal Reconstruction from Partial Phase and Magnitude Information

PRINCIPAL INVESTIGATOR

M. H. Hayes, Assistant Professor

SCIENTIFIC OBJECTIVE

Reconstructing a signal from only the phase or magnitude of its Fourier Transform are important problems which arise in a wide variety of different contexts and applications. Signal reconstruction from only magnitude information, for example, is a problem which naturally occurs in such diverse fields as crystallography, astronomy, and optics where the phase of an electromagnetic wave is either lost or impractical to measure and only intensity data is available. The ability to reconstruct a signal from only phase information, on the other hand, has potentially useful applications in such fields as seismics, ocean acoustics, radar and sonar signal processing, and image processing. Specifically, phase-only signal reconstruction techniques may be applied to the problems of deconvolution, time-delay estimation, system identification, spectral factorization, and phase unwrapping.

The long range goal of this research is to address some important questions and practical issues related to the phase-only and magnitude-only reconstruction problems for discrete multidimensional signals. Included in this work will be an investigation into the importance of "amplitude" information in the representation of signals, the development of some new approaches for reconstructing a signal from its spectral magnitude, a study of the sensitivity of phase-only reconstruction algorithms to measurement errors and computational noise and, finally, an investigation into possible approaches for robust signal reconstruction in the presence of noise. As a result of this work, some practical and important signal processing problems such as deconvolution will be re-examined in the context of phase-only or magnitude-only reconstruction.

RESEARCH ACCOMPLISHMENTS

As part of the long-range goal of this research, the importance of amplitude information in the representation of signals was addressed. In particular, it was shown that spectral amplitude, i.e., spectral magnitude along with one bit of phase information, is sufficient to uniquely define an arbitrary causal finite-length discrete-time signal. Consequently, spectral amplitude and the tangent of the spectral phase represent redundant pieces of information for most finite-length sequences. Furthermore, this result was shown to be related to some results in communication theory pertaining to the information contained in the zero crossings of band-limited signals. In particular, with sufficient delays it was shown that hard clipped phase contains all the information required to reconstruct a finite-length (time-limited) sequence.

Several iterative procedures were also investigated for reconstructing finite-length sequences from spectral amplitude. Although the correct solutions were always obtained with these algorithms, no theoretical proof of convergence is yet available.

WORK UNIT NUMBER 4

Title: Multiprocessor Architectures for Digital Signal Processing

Senior Principal Investigator: T. P. Barnwell, III, Professor

Scientific Personnel

C. J. M. Hodges, Research Engineer
Ken Clark, Graduate Research Assistant
Peter Yue, Graduate Student (Ph.D. candidate)
Mark Randolph, Undergraduate Student

Scientific Objectives

The objective of this research is to develop techniques for the automatic generation of optimal and near-optimal implementation of a large class of digital signal processing (DSP) algorithms on digital machines composed of multiple processors.

Research Accomplishments

This research is centered on the problem of generating efficient *implementations for* a large class of DSP algorithms using multiple programmable processors. This problem is fundamental in many areas including implementations using VLSI design, implementations using arrays of signal processing chips or microprocessors, and implementations using networks of general purpose computers.

DSP algorithms are unique in the sense that they generally have very high computational requirements and relatively simple control requirements. For this reason, it is often possible to use the system architecture and the system synchrony to intrinsically implement the control functions and to allow optimal utilization of the processors on pure arithmetic tasks. Traditionally, this problem has been approached from two poles: SIMD structures, where all the processors execute exactly the same program in lock-step; and "graph-structures", such as data flow machines, where the architecture is configured to the graph structure. The SIMD approach leads to very efficient implementations, but it is very inflexible. In contrast, fully implemented graph-structured machines achieve the maximum attainable thoughput (for a particular algorithm and processor), but are generally inefficient.

Our approach has been to study the overlap of a class of algorithms, a class of multiprocessors, and a class of implementations. The algorithms are all those techniques which can be specified by single time index signal flow graphs, and all algorithms which can be transformed into single time index signal flow graphs by restructuring or decimation. This class of algorithm includes all single and multiple dimension digital filters, time varying filter structures, sequential matrix operations, and many more. The class of multiprocessors are all those machines composed of identical, synchronous, programmable processors. The class of implementations is all those attainable by using the Skewed Single Instruction Multiple Data (SSIMD) approach. This is a hybrid SIMD pipeline approach which attains the efficiency of SIMD while being nearly as flexible as the graph-structured approach.

In this context, this years efforts have produced several major research results. First, a complete mathematical structure for describing the SSIMD mode has been developed, and expressions for limits in terms of throughput, number of processors, and communications structures have been found. Combining these results with results from graph theory, a theory which addresses the absolute optimality for implementations has been developed. Based on this theory, it has been proved that the SSIMD approach leads to optimal implementations for all nonrecursive and a very large class of recursive algorithms. Further, and most important, a set of rules have been specified for generating optimal SSIMD solutions from simple, non-parallel algorithm specifications. These rules have been verified using the multiprocessor computer previously constructed on this project.

In perspective, we feel that these results will have considerable impact in the next decade. What these results fundamentally represent is a systematic approach to the pipeline option in a form that is simple to use, elegantly controls the communications problem, and results in optimal solutions. At the current time, a fully automatic program generation system for our multiprocessor computer is being developed.

PUBLICATIONS

1. T. P. Barnwell, III, "Optimal implementation of recursive Signal flow graphs on Synchronous multiprocessor architectures," IEEE Workshop on Digital Signal Processing and VLSI, Santa Barbara, CA, Sept. 1981.

2. T. P. Barnwell, III and C. J. M. Hodges, "A synchronous multi-microprocessor system for implementing digital signal processing algorithms," Professional Program Session Record 21 of Southcon-82, pp. 21:4:1-21:4:6, March, 1982 (invited).

3. T. P. Barnwell, III, C. J. M. Hodges, and M. Randolph "Optimum implementation of single time index signal flow graphs on synchronous multiprocessor machines," To be presented at ICASSP-82, Paris, France, pp. 687-690, May, 1982.

WORK UNIT NUMBER 5

TITLE: Two-Dimensional Optical Storage and Processing

SENIOR PRINCIPAL INVESTIGATOR

Thomas K. Gaylord, Professor

SCIENTIFIC PERSONNEL

M. G. Moharam, Assistant Professor
C. C. Guest, Graduate Research Assistant (Ph.D. Candidate)
M. Mirsalehi, Graduate Research Assistant (Ph.D. Candidate)

SCIENTIFIC OBJECTIVE

The scientific objective of this research is to develop broadly-based, theoretical and experimental knowledge of high-capacity two-dimensional optical digital processing and two-dimensional optical information storage. This brings together a range of concepts from basic physics to signal processing in its most generalized form. Optical digital parallel processing in forms such as a word/signature detector, multiport memories, and a parallel numerical processor are being investigated.

RESEARCH ACCOMPLISHMENTS

As a part of the research sponsored by the Joint Services Electronics Program we have originated and developed a rigorous coupled-wave theory of grating diffraction. This new theory was published in July 1981 [1].

The rigorous coupled-wave theory allows the diffraction by gratings to be analyzed without approximations. This work has allowed, for the first time, simple and accurate grating diffraction calculations to be performed. These grating structures are widely used in laser beam deflection, guidance, modulation, coupling, filtering, wavefront reconstruction, and distributed feedback in the fields of acousto-optics, integrated optics, holography, quantum electronics, signal processing, and spectrum analysis.

By expanding the electric field in terms of space harmonics and substituting it into the wave equation, an infinite set of second-order coupled-wave equations is produced. We have applied the state variables approach from linear systems theory to solving this set of equations. This results in closed-form expressions for the space harmonic fields in terms of the eigenvalues and eigenvectors of the differential equation coefficient matrix. By applying the electromagnetic boundary conditions, a set of linear algebraic equations is obtained. This may then be solved for the forward and backward diffracted fields outside of the grating.

The rigorous coupled-wave method of analysis is straightforward to implement numerically. It has been implemented on large computers and on minicomputers. Even though this method was published only six months ago, it has already been widely used and copied by other universities and laboratories.

As a side benefit, the rigorous coupled-wave theory has been used by us to evaluate in detail, for the first time, the previous approximations (neglect of higher-order waves, neglect of second derivatives of field amplitudes, neglect of boundary effects, and neglect of dephasing) that are inherent in previous approximate theories such as 1) multiwave coupled-wave theory, 2) two-wave second-order coupled-wave theory, 3) two-wave modal theory, 4) two-wave first-order coupled-wave theory, 5) Raman-Nath theory, and 6) amplitude transmittance theory. The regimes of applicability for each of these approximate theories have now been analyzed by us.

Specific applications of the rigorous coupled-wave theory, of which we are aware, include optical digital parallel processing, acousto-optic signal processing, integrated optical spectrum analysis, and holographic head-up displays.

In summary, a new and exact theory of grating diffraction (rigorous coupled-wave theory) has been developed under JSEP sponsorship. This theory has already been widely cited and used by others.

PUBLICATIONS AND PRESENTATIONS

1. Moharam, M. G. and Gaylord, T. K., "Coupled-wave analysis of reflection gratings," Applied Optics, vol. 20, pp. 240-244, January 15, 1981.

2. Moharam, M. G. and Gaylord, T. K., "Rigorous coupled-wave analysis of planar grating diffraction," Journal of the Optical Society of America, vol. 71, pp. 811-818, July 1981.

3. Weaver, J. E. and Gaylord, T. K., "Evaluation experiments on holographic storage of binary data in electro-optic crystals," Optical Engineering, vol. 20, pp. 404-411, May/June 1981.

4. Gaylord, T. K., "Optics education is subject of special issue," Optical Engineering, vol. 19, pg. SR-148, September/October 1980.

5. Gaylord, T. K., Guest, C. C., and Gaylord, E. F., "Seven-segment representation of full ASCII and EBCDIC character sets," Computer, vol. 14, pp. 102-103, August 1981.

6. Gaylord, T. K. and Moharam, M. G., "Thin and thick gratings: terminology clarification," Applied Optics, vol. 20, pp. 3271-3273, October 1, 1981.

7. Gaylord, T. K., and Guest, C. C., Moharam, M. G., and Weaver, J. E., "Holographic data processing applications using photorefractive crystals," Ferroelectrics, vol. 35, pp. 137-142, 1981.

8. Gaylord, T. K. and Moharam, M. G., "Interrelationships between various planar grating diffraction theories," Journal of the Optical Society of America, vol. 71, pg. 1569, December 1981.

9. Moharam, M. G. and Gaylord, T. K., "Rigorous coupled-wave analysis of surface gratings with arbitrary profiles," Journal of the Optical Society of America, vol. 71, pg. 1573, December 1981.

10. Gaylord, T. K. and Moharam, M. G., "Planar dielectric grating diffraction theories," Applied Physics, vol. 16, pp. xxx-xxx, 1982, (invited).

11. Moharam, M. G. and Gaylord, T. K., "Chain matrix analysis of arbitrary-thickness dielectric reflection gratings," Journal of the Optical Society of America, vol. 72, pp. 187-190, February 1982.

PATENT

C. C. Guest and T. K. Gaylord, "Optical Holographic Content-Addressable Memory System for Truth-Table Look-Up Processing," U. S. Patent No. 4,318,581, issued March 9, 1982.

WORK UNIT NUMBER 6

TITLE: Hybrid Optical/Digital Signal Processing

SENIOR PRINCIPAL INVESTIGATOR

William T. Rhodes, Professor

SCIENTIFIC PERSONNEL

Mr. Joseph Mait, Graduate Research Assistant (Doctoral candidate)
Mr. Robert Stroud, Graduate Research Assistant (Doctoral candidate)

SCIENTIFIC OBJECTIVE

The overall goal of this work is the development of hybrid optical/electronic techniques for 2-D signal processing that complement existing and projected digital methods. Major areas of activity include (1) a theoretical investigation and the implementation of incoherent optical systems for bipolar spatial filtering; (2) the development of hybrid optical/electronic Fourier scanning techniques for highspeed image processing; (3) the investigation of partially coherent optical methods for adaptive fully parallel image enhancement; and (4) the investigation of general hybrid techniques for shift-variant 2-D signal processing.

RESEARCH ACCOMPLISHMENTS

Bipolar Incoherent Spatial Filtering. Constrainted iterative numerical methods have been developed for computer specification of coordinated pupil function pairs. A computer-controlled system is being employed for exposing test pupil transparencies for use in an imaging system.

Partially Coherent Image Processing. A versatile system for testing concepts and development techniques has been constructed and preliminary experiments have been conducted. Computer-generated masks will be used to control source and pupil distributions. We have discovered a new technique for linear-in-intensity imaging for coherent wave amplitude distributions that has implications for speckle reduction in laser radar and related fields.

Fourier Transform Scanning Image Processing. We have designed and are constructing a new system with which to conduct basic experiments.

Space-Variant Image Processing. (1) We have invented a new method for fully-parallel implementation of slowly space-varying linear processing operations for large space-bandwidth product imagery. (2) Effort has concentrated primarily on development of high-speed vector-matrix and matrix-matrix multiplication methods using acoustooptic devices.

PUBLICATIONS AND PRESENTATIONS

Conference Presentations (No Proceedings):

1. W. T. Rhodes, "Fourier transform scanning hybrid image processor," presented at ICO-12, Twelfth Congress of the International Commission for Optics, Graz, Austria, September 1981.

2. H. J. Caulfield and W. T. Rhodes, "Acoustooptic matrix-vector multiplication," presented at 1981 Annual Meeting of the Optical Society of America, Orlando, October 1981 (J. Opt. Soc. Am. 71, 1626, (1981) (A)).

Conference Presentations (Proceedings):

1. J. N. Mait and W. T. Rhodes, "Iterative design of pupil functions for bipolar incoherent spatial filtering," in Processing of Images and Data from Optical Sensors, W. Carter and G. Reynolds, eds., Proc. SPIE 292, 66-72 (1981).

2. H. J. Caulfield and W. T. Rhodes, "Optical implementation of systolic array processing," in Optical Information Processing for Aerospace Applications," NASA Conference, Langly, October 1981, NASA Conference Publication No. 2207.

3. A. Tarasevich, N. Zepkin, and W. T. Rhodes, "Matrix-vector multiplier with time-varying single dimensional spatial light modulators," in Optical Information Processing for Aerospace Applications, NASA Conference, Langly, October 1981, NASA Conference Publication No. 2207.

4. W. T. Rhodes, "Acoustooptic matrix-vector and matrix-matrix multiplication," in Proceedings of BMD/ATC Technical Interchange Meeting, Applications of Opto-Electronics, La Jolla, March 1982 (in press).

Journal Publications:

1. W. T. Rhodes, "Acoustooptic signal processing: convolution and correlation," Proc. IEEE 69, 65-79 (1981).

2. H. J. Caulfield, W. T. Rhodes, M. J. Foster, and S. Horvitz, "Optical implementation of systolic array processing," Opt. Commun. 40, 86-90 (1981).

Chapters in Books::

1. W. T. Rhodes and A. A. Sawchuk, "Incoherent Optical Processing," in Optical Information Processing: Fundamentals, S. Lee, ed. (Springer-Verlag, New York, 1981).

2. W. T. Rhodes, "The Falling Raster in Optical Signal Processing," in _Transformations in Optical Signal Processing_, W. Rhodes, J. Fienup, and B. Saleh, eds. (SPIE, Bellingham, 1982); in press.

3. W. T. Rhodes, "Space-Variant Processing," in _Applications of the Optical Fourier Transform_, H. Stark, ed. (Academic Press, New York, 1982).

WORK UNIT NUMBER 7

TITLE: Electromagnetic Measurements in the Time Domain

SENIOR PRINCIPAL INVESTIGATOR

G. S. Smith, Associate Professor

SCIENTIFIC PERSONNEL

Dr. J. D. Nordgard, Professor
Dr. L. N. An, Research Assistant (Through August 1981)
Mr. W. Scott, Graduate Research Assistant (Ph.D. candidate)

SCIENTIFIC OBJECTIVE

The broad objective of this research is to develop new methodology for making electromagnetic measurements directly in the time domain or over a wide bandwidth in the frequency domain. This research includes the development of theoretical analyses necessary to support the measurement techniques. One aspect of the research is the systematic study of radiating structures placed near or embedded in material bodies. In a practical situation the radiator might serve as a diagnostic tool for determining the geometry, composition or electrical constitutive parameters of the body.

RESEARCH ACCOMPLISHMENTS

The research on the single circular-loop antenna near a material interface was completed during this period; the results are described in the thesis and journal publications listed below. The analysis and measurements show that a single resonant loop, a fairly non directive antenna when isolated, when placed over a dielectric half-space can produce a very directive field in the dielectric. These results suggest that this antenna may be useful for sub-surface location and communication.

The results for the single loop were extended to analyze the coaxial array of circular loops near a half space. Preliminary calculations and measurements were made for the loop array.

The cylindrical monople antenna is being studied as a diagnostic probe for determining the electrical constitutive parameters of materials. General methods for inverting the measured admittance of electrically short antennas to determine the constitutve parameters have been developed, and an experimental program to validate the method by measuring the permittivity of temperature controlled liquids is in progress.

PUBLICATIONS AND PRESENTATIONS

1. L. N. An, "The eccentrically insulated circular-loop antenna and the horizontal circular-loop antenna near a planar interface," Ph.D. Thesis, Georgia Institute of Technology, Atlanta, Georgia, June 1981, 192 pages.

2. L. N. An and G. S. Smith, "The circular-loop antenna near a material interface," 1981 Spring URSI, IEEE AP-S Symposium, Los Angeles, California, June 1981.

3. L. N. An and G. S. Smith, "The horizontal circular-loop antenna near a planar interface, to be published in Radio Science, vol. 17, May-June 1982.

4. G. S. Smith and L. N. An, "Loop antennas for directive transmission into a material half-space," to be presented at the 1982 URSI Symposium, Albuquerque, New Mexico, May 1982.

WORK UNIT NUMBER 8

TITLE: Automated Radiation Measurements for Near and Far-field Transformations

SENIOR PRINCIPAL INVESTIGATOR

Edward B. Joy, Professor

SCIENTIFIC PERSONNEL

G. K. Huddleston, Associate Professor
W. M. Leach, Jr., Associate Professor
T. E. Brewer, Instructor
L. E. Corey, Graduate Research Assistant (Ph.D., December 1980)
B. E. Eis‿nman, Graduate Research Assistant (M. S., December 1980)
T. G. Picard, Graduate Research Assistant (M. S., June 1981)
R. E. Wilson, Graduate Research Assistant
G. R. Scott, Graduate Research Assistant

SCIENTIFIC OBJECTIVE

The objectives of this work are:

1.) Development of a general theory for probe position error compensation for near field measurements performed on arbitrary surfaces.

2.) Development of an indirect measurement method to determine the fields on the surface of a dielectric shell enclosing a radiating antenna to serve as an analytical tool in isolating deficiences in analysis methods.

3.) Development of a computationally efficient near field coupling equation between a test antenna and a measuring probe when the probe is used to sample the field radiated by the test antenna over the surface of a sphere.

RESEARCH ACCOMPLISHMENTS

An approximate technique for probe position error was formulated, computer implemented and demonstrated. Accuracy for small probe position errors was shown to be very good. This approximate technique known as "K-correction" is a phase only correction and based on the assumption of all near field energy propagating in the K-direction of the main beam peak. This technology was transferred to the RCA, U. S. Navy Aegis program and is now in use. Alignment of the Aegis phased array was judged impossible without this technology.

Efforts have been directed toward continued development of radome analysis methods based on geometrical optics for the determination of fields on the surface of a dielectric shell enclosing a radiating antenna. First order reflections and reflections from the antenna are being included for the first time. Significant aperture antenna synthesis work has also been done to accurately characterize the near fields of the actual antenna. Additional comparisons of predicted and measured radome performance have been done to further clarify deficiencies in current analysis methods.

An approximate solution to the near field coupling equation for spherical surface near field measurement systems has been obtained for a scalar field formulation. Work is in progress to extend this result to the vector field case.

Additional detail of these results are contained in the following publications:

JOURNAL ARTICLES

1. L. E. Corey and E. B. Joy, "On Computation of Electromagnetic Fields on Planar Surfaces from Fields Specified on Nearby Surfaces," IEEE Transactions on Antennas and Propagation, Vol. Ap-29, No. 2, March 1981, pp. 402-404.

CONFERENCE PROCEEDINGS

1. E. B. Joy, "Signal Processing in Electromagnetic Radiation Measurements," Proceedings of the IEEE International Circuits and Systems Symposium, Chicago, IL, April 27-29, 1981.

2. E. B. Joy, "Current Near-Field Measurement Research Activities at Georgia Tech," Proceedings of the Antenna Measurements Techniques Association Meetings, Danvers, MA, October 13-15, 1981.

3. E. B. Joy and G. R. Scott, "Shape Effects on Optimal Radome Wall Design," Proceedings of the Sixteenth Symposium on Electromagnetic Windows, June 1982, Atlanta, Georgia.

4. G. K. Huddleston and J. M. Roe, "Aperture synthesis of Monopulse Antenna for Radome Analysis Using Limited Measured Pattern Data," Proceedings of SPIE, Vol. 294, August 1981, pp. 113-118.

5. G. K. Huddleston, "Effects of ray refraction and reflection on radome boresight error calculations using geometrical optics and Lorentz reciprocity," Proceedings of Sixteenth Symposium on Electromagnetic Windows, June 1982.

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